Memorandum

To: Jesse Wijntjes, *FAA AUA-200*

CC: Accuracy Working Group List (see attached list)

From: Mike Paglione, *FAA ACT-250*

Date: 1/22/02[1]

Re: **URET Weather Analysis - Preliminary Phase Zero Results**

Executive Summary

The User Request Evaluation Tool (URET) uses forecasted weather data to build its aircraft trajectories. Forecasted weather will never be entirely correct and becomes increasing inaccurate with forecast age. In April of 1997, MITRE Center for Advanced Aviation System Development (CAASD) performed an analysis to assess the impact on URET algorithmic performance due to the absence of weather forecasts [1]. Although MITRE CAASD concluded that the absence of weather forecasts (i.e. zero winds and standard atmospheric temperature) produced little difference in the conflict predictions, they did show the longitudinal trajectory error difference between the no wind and a baseline URET run increased significantly beyond four minutes in trajectory age. This difference in trajectory accuracy was also linked to an increase in the number of trajectory re-conformances and a larger number of marginal conflict predictions.

Building on the work the MITRE CAASD researchers performed in references [1] and [2], the Federal Aviation Administration's Engineering and Integration Services Branch (ACT-250) has been sponsored by the Free Flight Phase One Program Office (AOZ-200) to examine the impact of degraded weather forecasts on URET predictions, in particular the aircraft trajectories and conflict predictions generated from them. ACT-250's objective was not only to determine the impact of degraded weather forecasts on URET but also provide the facilities with guidance when they suspect this has occurred.

The weather files used by URET provide numerous weather data at grid points across the continental United States. ACT-250 has obtained and developed tools that can isolate and modify the weather data at each grid point for a selected regional area (e.g. around a center boundary). Therefore, ACT-250 can alter a weather file by specified quantity and compare URET predictions against a non-altered run. Using this technique, ACT-250 plans to analyze the URET accuracy effects from weather forecast error with a three-phase study during fiscal year 2002. The first is Phase Zero. Phase

[1] ACT-250 updated the memo slightly on 2/3/02 by adding hyperlinks to relevant references and correcting typo in footnote 2.

Zero is a discovery phase where a small set weather levels are selected for the experiment. The purpose is to test the tools developed to alter weather files, to select meaningful descriptive statistics to characterize the weather, to generate some preliminary results that might aid in setting levels for weather variables for the larger Phase One study. Phase One will be a follow-on study that will use multiple weather variables and various levels of these variables. Finally, Phase Two will examine the URET sensitivity to actual convective weather, thereby conditions where the weather forecasts are in error and traffic is re-routed considerably.

This memorandum reports on preliminary results from the Phase Zero Study where trajectory accuracy was examined when altering wind magnitude only. Similar to the MITRE reference [1] results, ACT-250 found significant longitudinal trajectory accuracy degradation when altering the wind magnitude by only 30 knots. However, ACT-250 went even further by partitioning the trajectory accuracy by vertical phase of flight. Although the 30 knots wind error had not been statistically significant on vertical error for all measurements when the data was partitioned by vertical transition and level flight, there was a statistically significant effect during the transitioning measurements. It is suspected that this effect on vertical error for transitioning flight, although small, was caused by the same wind induced speed inaccuracy as found for the longitudinal error during all phases. These results are preliminary, but do illustrate the progress ACT-250 has made in developing tools to alter weather forecast variables and techniques it can apply to determine the effects on URET prediction accuracy. The work will continue to expand in the execution of the described three phases of the study. The next steps of Phase Zero will be to explore other weather variables used by URET (i.e. wind direction and air temperature) for both trajectory and conflict prediction accuracy.

Current Methodology[2]

The experiment was to run recorded traffic data through URET with the altered NWS Rapid Update Cycle (RUC) files, perform trajectory analysis and compare the results with those for a run with unaltered RUC files. Trajectory accuracy was determined using ACT-250 tools (described in references [3] and [4]), which provided information on horizontal, vertical, longitudinal and lateral trajectory error. Statistical Analysis System (SAS) software was used to generate statistical summary analysis and to test the hypothesis of no statistical difference between runs. The outline below provides the procedure used to generate the trajectory data and analysis.

1. A two hour track segment was selected from data recorded for ZME Center on 5/26/1999. The hours selected were 1800 to 2000 Zulu time.

2. The segment was run through URET with the original RUC files to generate trajectories. The horizontal, vertical, longitudinal and lateral error between track and trajectory was determined for each track point using ACT-250 tools. A database table was populated with aircraft ID, look ahead time, phase of flight, horizontal, vertical, longitudinal and lateral errors.

3. The RUC files were altered by adding 30 knots to the recorded wind magnitude vector at each grid point for an area extending beyond the ZME Center. The capability to alter RUC files results from new ACT-250 tools.

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[2] Special thanks to Bill Dudzik at AST Engineering Services (AUA-200 support contractor) who provided significant guidance to ACT-250 into the various shareware tools available to process NWS RUC files.

4. The original segment was run through URET a second time with the altered RUC files. The accuracy tools were run using the new trajectories and the error results written to another database table.

5. Files for the two runs were imported to a spreadsheet, sorted by aircraft ID, look ahead time and phase of flight. The files were next matched by aircraft ID and the difference between the two runs for each error type was recorded. The difference was calculated as control minus treatment.

6. A table containing the error differences was imported into both SAS and SAS-JMP (SAS graphical statistical package). A statistical analysis was done for each error type and phase of flight (level, in transition or all flights). Results include a descriptive summary of the error data and various hypothesis tests of no statistical difference between the two runs.

Results

The results consist of Figures 1-4 provided in Appendix A, Figures 5-16 in Appendix B and Tables 1-12 in Appendix C. Figures 1-4 are plots of the mean difference between the various trajectory error types for flights in transition, not in transition and for all flights regardless of transition. Figures 5-16 are plots of the data and quantiles by error and flight type. Tables 1-12 provide extensive statistics for the difference in trajectory accuracy difference by error type, phase of flight combination, and look ahead time. There are twelve combinations of error type and phase of flight.

Before describing the results in detail, some overall observations and notes are worth discussion. These include the following:

- There was limited data for flights in transition with the larger look ahead (LH) times (18 observations for LH600, 3 observations for LH900, no data for LH1200). Statistical analysis based on these small sample sizes (i.e. LH600 and above) is not reliable.

- The results are the difference in measured trajectory errors for the same track point using two different weather forecasts. This is NOT a measure of trajectory error but of the difference between trajectory errors. Thus, this analysis focuses on the effect of induced wind error on the various trajectory errors and how they were partitioned.

- The results are the control run minus treatment run. The control run used the original RUC file. The treatment run used a RUC file with plus 30 knots added to wind magnitude. A negative result indicates that the treatment error was larger than the control error.

- A nonparametric test of hypothesis was used because the distribution of errors was not normally distributed for any error type. The standard t-test is valid where the data distribution is known to be normally distributed. By default SAS summary statistics includes the t-test, sign test and signed-rank test. The last two tests are nonparametric equivalents of the t-test.

- A statistical test provides evidence supporting one of two alternative hypotheses. The null hypothesis states that the difference between control and treatment is not statistically different from zero. The alternative hypothesis states that this difference is too large to be considered statistically the same.

- The test values provided in the statistical summary tables are known as p-values. A p-value is the probability of seeing a difference this large given that the null hypothesis is true. A value of five percent (0.05) or smaller is generally taken as support for the alternative hypothesis.

- The median and range become better estimates of sample location and variability when the data contains outliers. An outlier is an observation that is not consistent with the bulk of the data. Outliers are not necessarily bad data points and require investigation.

- Skewness and Kurtosis are measures of symmetry and shape for distributions. A negative value for skewness reveals a longer left tail and a positive value a longer right tail. A high value for kurtosis indicates heavy tails or a large number of data points in the tails if the distribution. As a reference, the kurtosis of a normal distribution is zero.

Figures 1-3 (all data, level and transitioned flight data) show that the difference in longitudinal error follows closely with the difference in horizontal error. Both measurements become increasingly negative with look ahead (LH) time. The measurement is control minus treatment so a negative value indicates that the treatment measurement is increasing faster than the control measurement. Figure 1 (all flights data) and Figure 2 (level flights data) appear identical because most of the data is in level flight. The plots show that the difference in lateral error is never greatly different from zero for phase of flight.

Figure 4 (vertical flight data) indicates that vertical error is never greatly different from zero. Note that the scale for this measure is in feet and that the absolute maximum is around eleven feet occurring at LH300.

Figures 5-8 (data and quantile plots for all flights) - Figure 5 (difference in horizontal error) and Figure 7 (difference in longitudinal error) both show data spread increasing with LH time. The quantiles indicate the distributions are relatively symmetrical but skewed left (data has a greater spread in the left tail). Figure 6 (difference in lateral error) and Figure 8 (difference in vertical error) are strongly peaked with the bulk of the data centered at zero.

Figures 9-12 (data and quantile plots for level phase) - The results are essentially the same as described for data from all flights. This is to be expected as most of the total data was in level phase. Plots for horizon and longitudinal error show an increase in data spread with LH time. The vertical and lateral plots show strong peaks centered at zero.

Figures 13-16 (data and quantile plots for transition phase) - The results again show data skewed-left with an increasing spread with LH time for horizontal and longitudinal error and strong peaks for lateral and vertical error. There was insufficient data above LH600 to show any definitive data structure.

Table 1 (horizontal error and all flights) - The mean and median become increasingly negative with LH. The standard deviation and range both increase with LH. The Skewness is negative indicating that the distribution has an elongated tail to the left or towards the negative values. This observation and that for the range are shown also in the Max and Min values of the quantiles where the minimum value is negative and larger in the absolute value than the maximum value which is positive. The difference between the Max and Min increase with LH. The Signed Rank (SR) test indicates that the results are not significantly different from zero at LH0 but are different at other LH times.

Table 2 (lateral error and all flights) - The mean is positive but close to zero and approaches zero with LH. The median is always zero. The standard deviation and range both decrease with LH. The distributions are skewed both left and right but probably affected by outliers as the upper and lower quantiles (captures 75 and 25 percent of the data) are both zero. The quantile pattern indicates strongly peaked distributions. The SR test is not significantly different from zero for any LH.

Table 3 (longitudinal error and all flights) - The mean and mode are both negative and increase (become more negative) with LH. The standard deviation and range increase with LH. Skewness is not significantly different from zero (sample distribution is symmetric about zero). The SR test is not significantly different from zero at LH0 ($p = 0.1135$) but is significant at other LH times.

Table 4 (vertical error and all flights) - The mean is both positive and negative but not significantly different from zero given the scale. The median is zero for each LH time. The standard deviation and range are relatively constant at around 200 and 3500 feet respectively. The quantiles indicate a strongly peaked distribution. The SR test is not significant for any LH ($p = 0.0823$ for LH300).

Table 5 (horizontal error and level flight) - Both the mean and median start at zero and become increasingly negative with LH. Standard deviation and range increase with time. Skewness is always negative but essentially zero. The SR test is not significant at LH0 but is significant otherwise.
Table 6 (lateral error and level flight) - Both the mean and median are essentially zero or equal zero for all LH. The standard deviation and range both increase with LH. The skewness and quantiles show the same pattern as in Table 2. The distributions are again strongly peaked. The SR test indicates is not significant for any LH ($p = 0.0914$ at LH1200).

Table 7 (longitudinal error and level flight) - The mean and median are both negative and increase (more negative) with LH. The standard deviation and range are both positive and increase with LH. The SR test is not significant for LH0 or LH300 ($p = 0.1014$ at LH300) but is significant for the remaining LH times.

Table 8 (vertical error and level flight) - The mean and median are both essentially zero or equal to zero. The standard deviation and range are around 150 and 2500 feet respectively. The distributions are strongly peaked with the upper and lower quantiles equal to zero. The SR test is not significant for any LH time.

Table 9 (horizontal error and transition flight) - Considering results for LH0 and LH300 only, the mean and median are both negative and increase with LH. The standard deviation is slightly larger at LH300 but both are close to zero. The range is smaller for LH300. The SR test is not significant for either LH time or for LH600. There is no data for LH1200.

Table 10 (lateral error and transition flight) - The mean is close to zero. The median equals zero. The standard deviation and range both decrease with LH. The data are skewed right at LH0 and left at LH300. The SR test is not significant for either LH Time.

Table 11 (longitudinal error and transition flight) - The mean and median are both negative and increase with LH300. The standard deviation increase at LH300 while the range decreases. The data is skewed left at LH0 and right at LH300. The SR test is significant for both times.

Table 12 (vertical error and transition flight) – The mean is positive and increases with LH. The median is always zero. The standard deviation and range are around 400 and 3300 feet respectively. The SR test is not significant for LH0 but is significant for LH300. The test is again not significant at LH600 based on 18 data samples.

Conclusions

One of the most significant findings of this preliminary study is the impact on longitudinal trajectory error by a wind error of only 30 knots in magnitude. These findings are consistent with MITRE CAASD results in references [1] and [2]. ACT-250 believes this impact on trajectory accuracy is therefore related to the URET predicted speed calculations. Thus, a wind induced error will cause a proportional error in the predicted speed and at the larger look ahead times (beyond five minutes) this error increases in horizontal and longitudinal trajectory accuracy errors. This is illustrated by an increasing negative mean error difference in Figures 1-3. The lateral and vertical errors show little change and are not statistically different than zero (meaning no impact by wind). In Figures 5-8, the horizontal and longitudinal error difference between the control and wind altered runs illustrate a substantial increase in variance as the look ahead time increases, while the lateral and vertical diagrams show little variation at all, which center on zero at every LH.

The results for all flights and samples only showing a significant impact on horizontal and longitudinal trajectory errors do change if the data is partitioned by vertical phase of flight. In Figure 4, the mean difference in vertical error increases as look ahead time increases. However, the sample size for transition trajectory data decreases dramatically making any claims on LH of 600 seconds and above unusable. ACT-250 believes this is caused by the interaction of the truncation of a LH window by a clearance and the climb or descent of an aircraft. In other words, an aircraft is first cleared to descend or climb and this occurs as LH increases. This situation dominates the data. The remaining situations after the clearance, which are not truncated (after the LH window steps over the clearance, see reference [4]), do illustrate an effect by the wind error in Figure 4 and Figures 13-16. These are statistically significant for the same reasons the longitudinal errors were in the all flights analysis. During transitioning flight, longitudinal and vertical errors interact in which an error in one of them will cause the error in the other, however during level flight these errors are fairly independent. As shown in the sample size field (N) in Tables 1-12, the level flight samples dominate the trajectory data. Therefore, the all flight analysis showed no statistical effect on the vertical trajectory accuracy and only when the data is partitioned is the vertical error significant.

Once again these findings are not different from the MITRE CAASD results in reference [1] and are just preliminary, but do illustrate the progress ACT-250 has made in developing tools to alter weather forecast variables and techniques it can apply to determine the effects on URET prediction accuracy. The work will continue to expand in the execution of the described three phases of the study. The next steps of Phase Zero will be to explore other weather variables used by URET (i.e. wind direction and air temperature) for both trajectory and conflict prediction accuracy.

References

1. "Sensitivity of AEC/URET Performance to Wind Data," MITRE CAASD Memorandum F042-M087, Lindsay, K. S., April 21, 1997.

2. "Analysis of Differences Between Wind Forecasts Using RUC-211 and RUC-236 Grids," MITRE CAASD Memorandum F042-M-113, Cordova, S., Lindsay, K. S., November 3, 2000.

3. *Trajectory Prediction Accuracy Report: URET/CTAS* (DOT/FAA/CT-TN99/10), Paglione, M. et. al., WJHTC/ACT-250, May 1999 (http://www.act250.tc.faa.gov/cpat/docs/trjrpt_f2.pdf).

4. "A Generic Sampling Technique For Measuring Aircraft Trajectory Prediction Accuracy", Cale, M., Liu, S., Oaks, R., Paglione, M., Ryan, H., Summerill, S., USA/Europe ATM R&D Seminar, Santa Fe, New Mexico, December 2001 (http://atm2001.eurocontrol.fr/).

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[3] Accuracy working group list includes all participants involved on URET CCLD accuracy measurement. Email sent to the ACT-250 email account, accuracy@tatca.tc.faa.gov, will be forwarded to everyone in the list.

Appendix A – Plots of the Mean Difference in Errors by LH Time for Phase of Flight

Figure 1: Mean Diff Err for All Flights

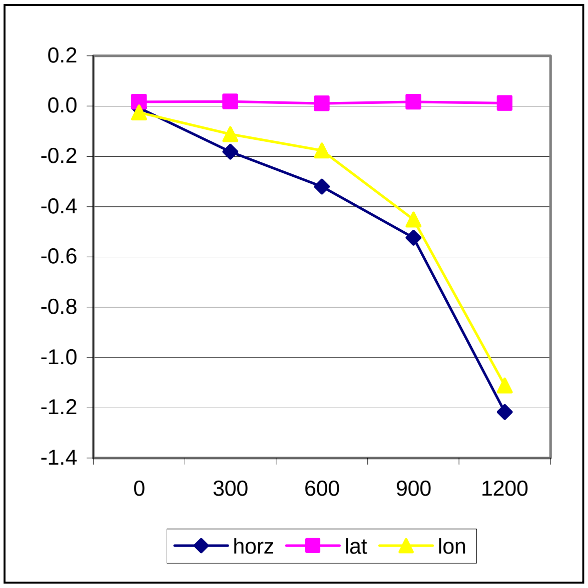


Figure 2: Mean Diff Err for Level Flight

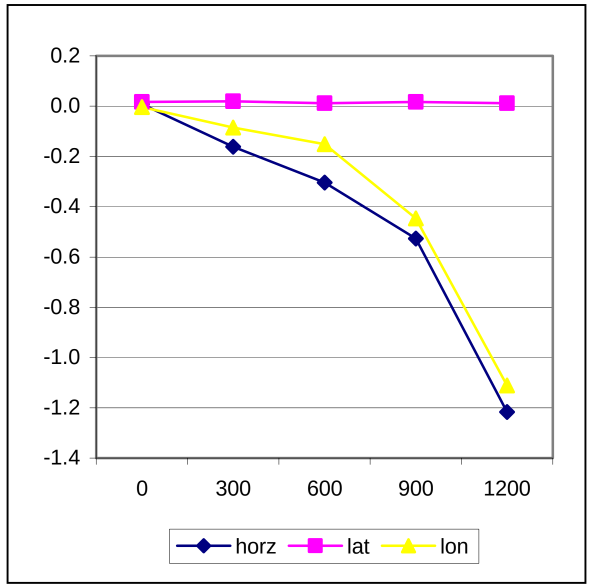


Figure 3: Mean Diff Err for Trans Flights

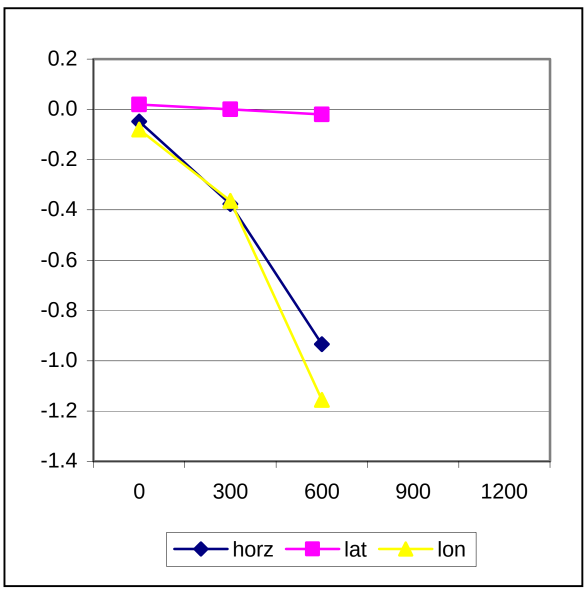
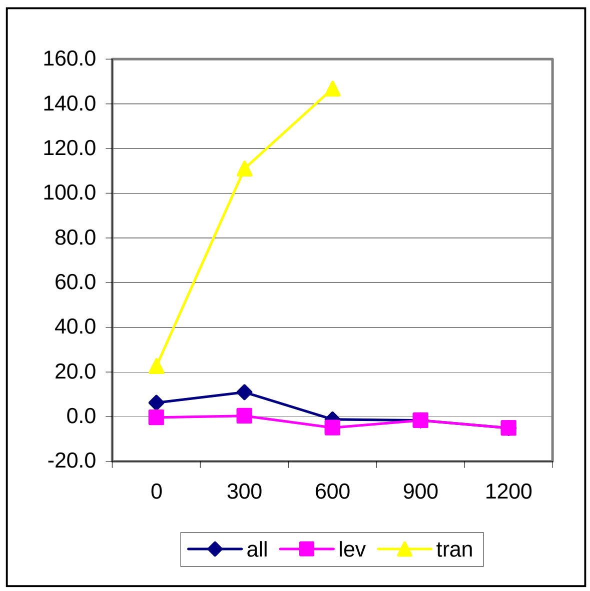


Figure 4: Mean Diff for Vertical Error



Appendix B – Plots of Data and Quantiles by Error and Flight Type

- **Results for All Flights**

Figure 5: Diff in Horz Err by LH Time

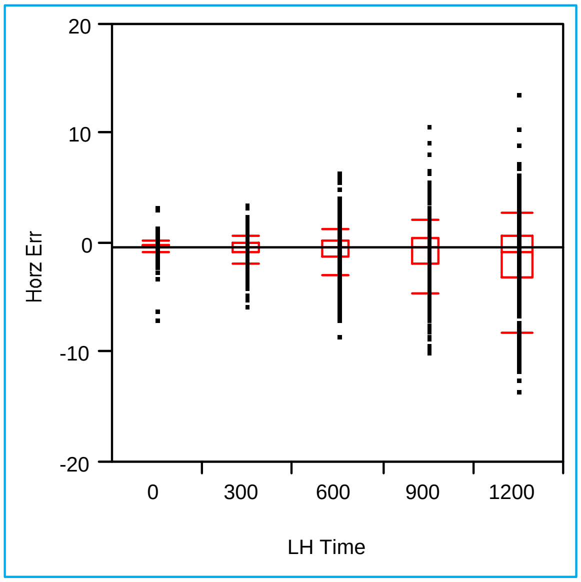


Figure 6: Diff in Lat Err by LH Time

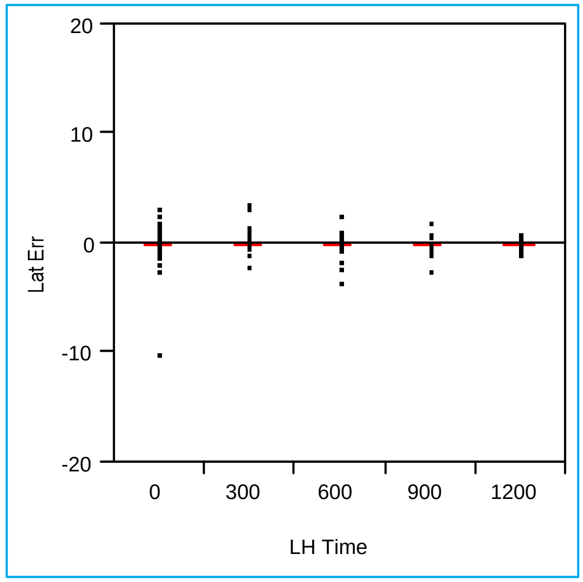


Figure 7: Diff in Lon Err by LH Time

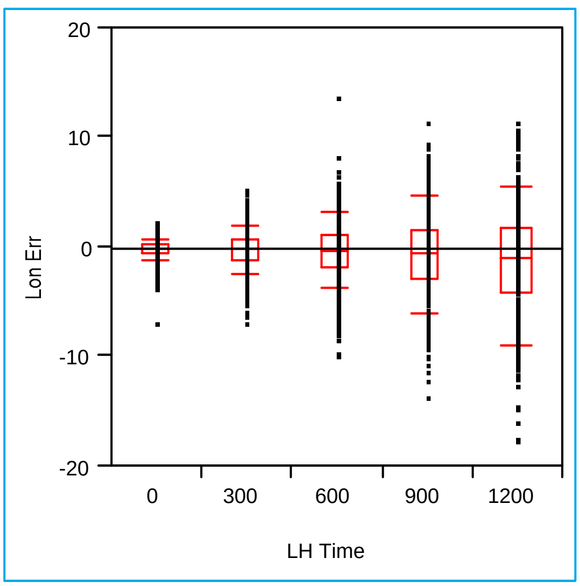
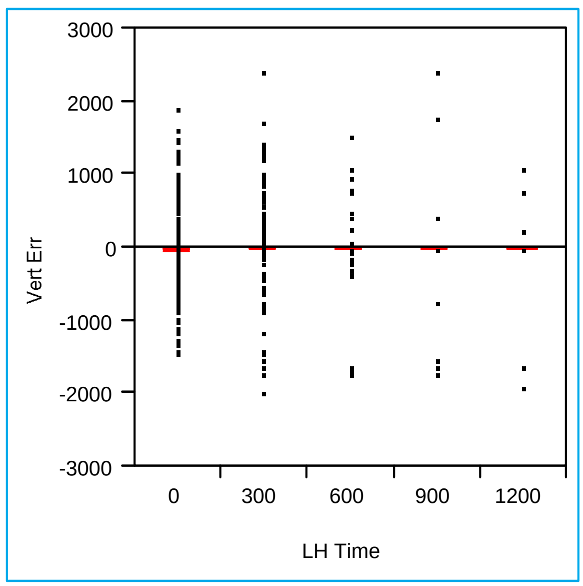


Figure 8: Diff in Vert Err by LH Time



- **Results for Level Flights**

Figure 9: Diff in Horz Err by LH Time

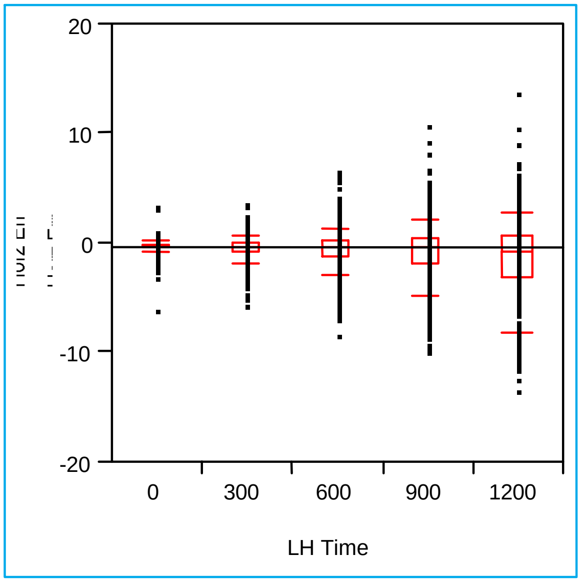


Figure 10: Diff in Lat Err by LH Time

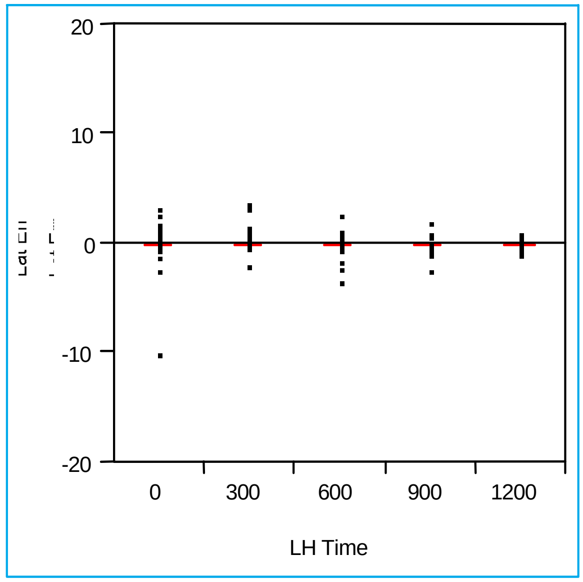


Figure 11: Diff in Lon Err by LH Time

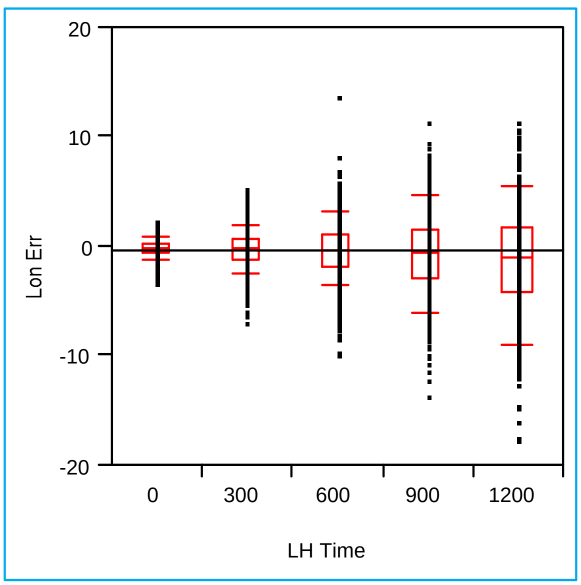
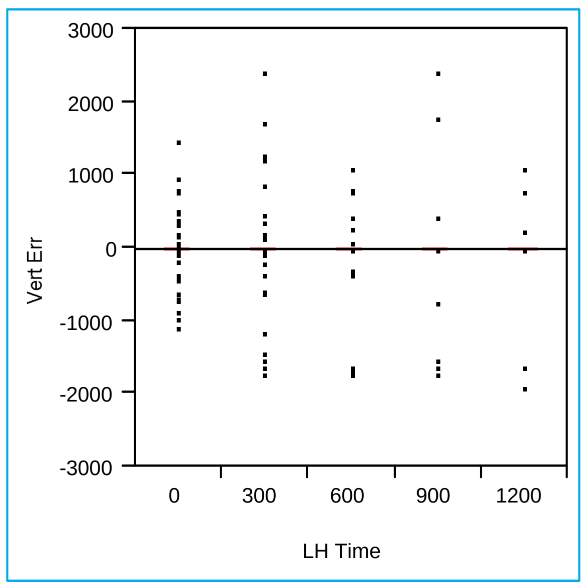


Figure 12: Diff in Vert Err by LH Time



- **Results for Transitioned Flights**

Figure 13: Diff in Horz Err by LH Time

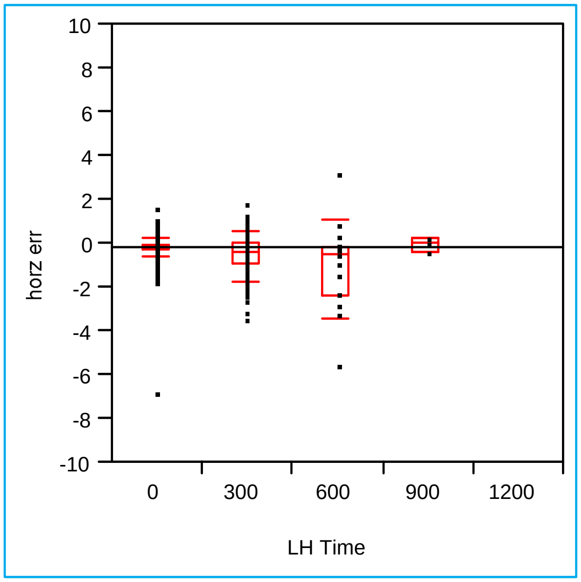


Figure 14: Diff in Lat Err by LH Time

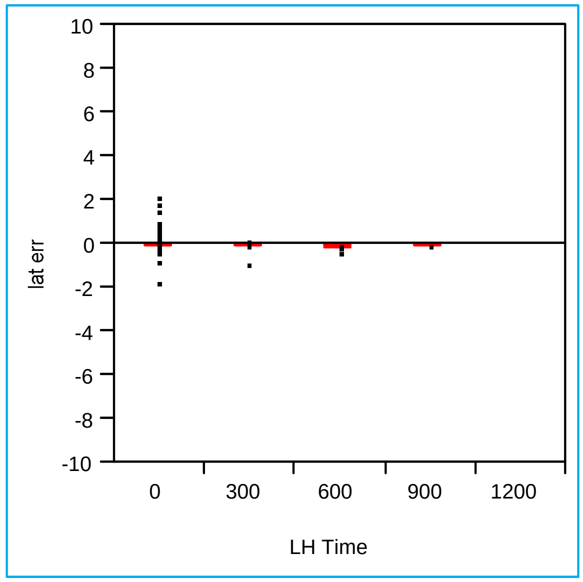


Figure 15: Diff in Lon Err by LH Time

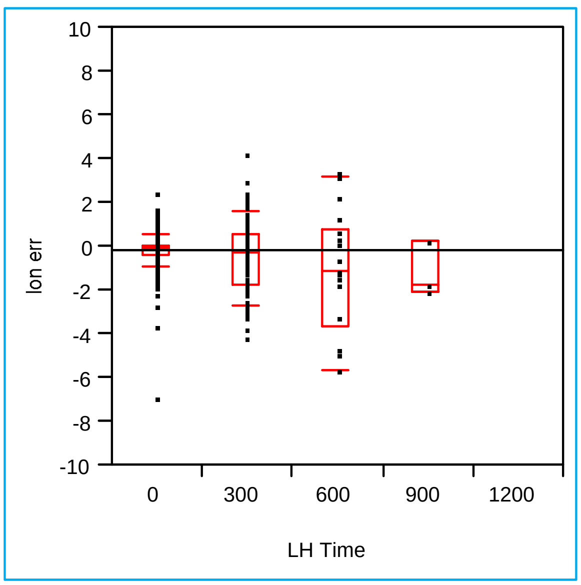
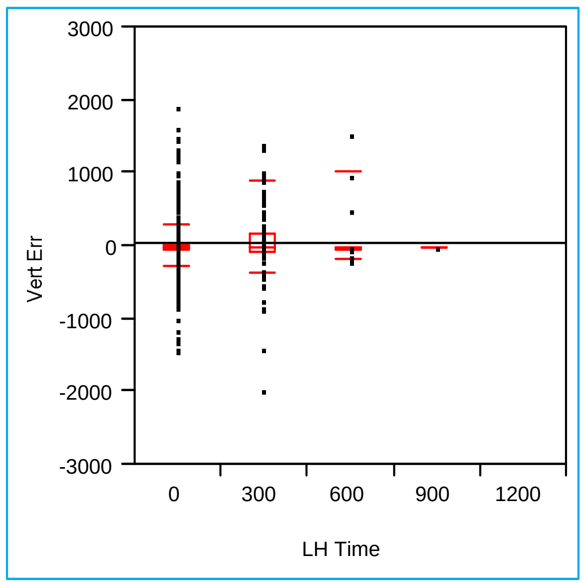


Figure 16: Diff in Vert Err by LH Time



Appendix C – Statistical Summary Tables by Error and Flight Type

Table 1: Univariate Statistics for Horizontal Error and All Flights

Horizontal Error All Flights		Look Ahead Time 0	300	600	900	1200
Location	N	1817	1099	722	503	340
	Mean	-0.00784	-0.18189	-0.32017	-0.52333	-1.21627
	Median	0.00000	-0.06100	-0.10000	-0.20680	-0.56390
	Mode	0.00000	0.00000	-0.87790	0.72810	-0.91260
Variability	Std Dev	0.46528	1.05893	1.86365	2.86646	4.01497
	Variance	0.21649	1.12133	3.47319	8.21660	16.11996
	Range	10.40140	9.36360	15.03230	20.73360	27.23340
Moments	Skewness	-2.559008	-0.4472892	-0.3674881	-0.4244133	-0.4645545
	Kurtosis	43.5219177	2.26814989	2.24685326	1.80850454	1.06092041
Test for Location	Student T	0.4726	0.0001	0.0001	0.0001	0.0001
	Sign	0.2236	0.0001	0.1460	0.0125	0.0028
	Signed Rank	0.6315	0.0001	0.0001	0.0008	0.0001
Quantiles	Max	3.6347	3.9493	6.8494	10.9991	13.95030
	75%	0.1265	0.3263	0.5091	0.8121	0.93775
	50%	0.0000	-0.0610	-0.1000	-0.2068	-0.56390
	25%	-0.1317	-0.6131	-0.9825	-1.5139	-2.96860
	Min	-6.7667	-5.4143	-8.1829	-9.7345	-13.28310

Table 2: Univariate Statistics for Vertical Error and All Flights

Lateral Error All Flights		Look Ahead Time 0	300	600	900	1200
Location	N	1817	1099	722	503	340
	Mean	0.016987	0.017806	0.010365	0.016448	0.011275
	Median	0.000000	0.000000	0.000000	0.000000	0.000000
	Mode	0.000000	0.000000	0.000000	0.000000	0.000000
Variability	Std Dev	0.32034	0.21153	0.22454	0.20937	0.12882
	Variance	0.10262	0.04474	0.05042	0.04384	0.01660
	Range	13.40090	5.70980	5.98700	4.47130	1.93750
Moments	Skewness	-13.313144	11.0574017	-1.2131673	3.01502946	3.80391523
	Kurtosis	518.003377	183.473829	108.835601	78.7314914	45.0712694
Test for Location	Student T	0.0239	0.0054	0.2153	0.0787	0.1075
	Sign	0.0475	0.2643	0.0361	0.3384	0.7376
	Signed Rank	0.7195	0.7848	0.7875	0.5529	0.0914
Quantiles	Max	3.5707	3.8944	2.7700	2.1943	1.11510
	75%	0.0000	0.0000	0.0000	0.0000	0.00000
	50%	0.0000	0.0000	0.0000	0.0000	0.00000
	25%	0.0000	0.0000	0.0000	0.0000	0.00000
	Min	-9.8302	-1.8154	-3.2170	-2.2770	-0.82240

Table 3: Univariate Statistics for Longitudinal Error and All Flights

Longitudinal Error All Flights		Look Ahead Time 0	300	600	900	1200
Location	N	1817	1099	722	503	340
	Mean	-0.02525	-0.11130	-0.17675	-0.45063	-1.11142
	Median	-0.00400	-0.08600	-0.26865	-0.45730	-0.87515
	Mode	0.00000	0.00000	-0.79780	-1.09870	-5.35710
Variability	Std Dev	0.76936	1.65411	2.71560	3.94202	5.35582
	Variance	0.59192	2.73608	7.37450	15.53952	28.68478
	Range	9.41470	12.14150	23.64010	25.06340	29.00580
Moments	Skewness	-0.4710786	-0.0698699	0.1151388	-0.0799959	-0.1929441
	Kurtosis	4.18588847	0.52066575	1.27532754	0.47737397	0.16462498
Test for Location	Student T	0.1620	0.0259	0.0807	0.0106	0.0002
	Sign	0.0238	0.0058	0.0003	0.0001	0.0009
	Signed Rank	0.1135	0.0276	0.0312	0.0062	0.0005
Quantiles	Max	2.6057	5.4231	13.87750	11.5940	11.59990
	75%	0.3297	0.8693	1.35040	1.7728	1.88600
	50%	-0.0040	-0.0860	-0.26865	-0.4573	-0.87515
	25%	-0.3792	-1.0828	-1.72540	-2.6312	-3.91120
	Min	-6.8090	-6.7184	-9.76260	-13.4694	-17.40590

Table 4: Univariate Statistics for Vertical Error and All Flights

Vertical Error All Flights		Look Ahead Time 0	300	600	900	1200
Location	N	1817	1099	722	503	340
	Mean	6.238133	10.86626	-1.18917	-1.65939	-5.06999
	Median	0.000000	0.00000	0.00000	0.00000	0.00000
	Mode	0.000000	0.00000	0.00000	0.00000	0.00000
Variability	Std Dev	200.13704	221.27370	157.23725	188.17223	187.71764
	Variance	40055	48962	24724	35409	35238
	Range	3363	4411	3270	4166	3028
Moments	Skewness	1.57048648	1.28577962	-3.6039971	2.38891078	-5.0460949
	Kurtosis	27.7636655	43.6684335	86.5313898	105.622733	67.5558017
Test for Location	Student T	0.1841	0.1038	0.8390	0.8433	0.6188
	Sign	0.9241	0.3729	1.0000	1.0000	1.0000
	Signed Rank	0.7472	0.0823	0.9063	1.0000	0.5781
Quantiles	Max	1941.8109	2453.2242	1563.076	2453.22	1134.832
	75%	0.0000	0.0000	0.000	0.00	0.000
	50%	0.0000	0.0000	0.000	0.00	0.000
	25%	0.0000	0.0000	0.000	0.00	0.000
	Min	-1420.7829	-1957.5000	-1706.712	-1713.09	-1892.755

Table 5: Univariate Statistics for Horizontal Error and Level Flight

Horizontal Error Level Flight		Look Ahead Time 0	300	600	900	1200
Location	N	1300	994	704	500	340
	Mean	0.008004	-0.16135	-0.30446	-0.52709	-1.21627
	Median	0.000000	-0.04710	-0.09205	-0.20810	-0.56390
	Mode	0.000000	0.00000	-0.87790	0.72810	-0.91260
Variability	Std Dev	0.45910	1.06704	1.86095	2.87458	4.01497
	Variance	0.21078	1.13857	3.46313	8.26319	16.11996
	Range	9.52000	9.36360	15.03230	20.73360	27.23340
Moments	Skewness	-1.2753445	-0.4476372	-0.3705904	-0.419519	-0.4645545
	Kurtosis	28.1853111	2.34757143	2.30265324	1.78090565	1.06092041
Test for Location	Student T	0.5297	0.0001	0.0001	0.0001	0.0001
	Sign	0.5343	0.0050	0.2737	0.0107	0.0028
	Signed Rank	0.2175	0.0001	0.0003	0.0007	0.0001
Quantiles	Max	3.63470	3.9493	6.84940	10.99910	13.95030
	75%	0.16970	0.3450	0.52110	0.81515	0.93775
	50%	0.00000	-0.0471	-0.09205	-0.20810	-0.56390
	25%	-0.13620	-0.5896	-0.96375	-1.52115	-2.96860
	Min	-5.88530	-5.4143	-8.18290	-9.73450	-13.28310

Table 6: Univariate Statistics for Lateral Error and Level Flight

Lateral Error Level Flight		Look Ahead Time 0	300	600	900	1200
Location	N	1300	994	704	500	340
	Mean	0.016182	0.019711	0.011140	0.016546	0.011275
	Median	0.000000	0.000000	0.000000	0.000000	0.000000
	Mode	0.000000	0.000000	0.000000	0.000000	0.000000
Variability	Std Dev	0.35899	0.22071	0.22705	0.20999	0.12882
	Variance	0.12887	0.04871	0.05155	0.04410	0.01660
	Range	13.40090	5.70980	5.98700	4.47130	1.93750
Moments	Skewness	-13.552381	10.7818768	-1.2095862	3.00483361	3.80391523
	Kurtosis	456.785554	170.536629	106.744277	78.2490144	45.0712694
Test for Location	Student T	0.1043	0.0050	0.1934	0.0787	0.1075
	Sign	0.2093	0.1722	0.0474	0.3384	0.7376
	Signed Rank	0.5906	0.8002	0.9611	0.5529	0.0914
Quantiles	Max	3.57070	3.8944	2.7700	2.19430	1.11510
	75%	0.00000	0.0000	0.0000	0.00000	0.00000
	50%	0.00000	0.0000	0.0000	0.00000	0.00000
	25%	0.00000	0.0000	0.0000	0.0000	0.00000
	Min	-9.83020	-1.8154	-3.2170	-2.27700	-0.82240

Table 7: Univariate Statistics for Longitudinal Error and Level Flight

Longitudinal Error Level Flight		Look Ahead Time 0	300	600	900	1200
Location	N	1300	994	704	500	340
	Mean	-0.00323	-0.08462	-0.15172	-0.44668	-1.11142
	Median	-0.00270	-0.08050	-0.25865	-0.43860	-0.87515
	Mode	0.00000	0.00000	-0.79780	-1.09870	-5.35710
Variability	Std Dev	0.79380	1.65585	2.70845	3.95269	5.35582
	Variance	0.63012	2.74184	7.33571	15.62374	28.68478
	Range	5.81040	12.14150	23.64010	25.06340	29.00580
Moments	Skewness	-0.704547	-0.0830417	0.12388546	-0.0826682	-0.1929441
	Kurtosis	0.72945394	0.60889846	1.34341794	0.46097992	0.16462498
Test for Location	Student T	0.8833	0.1075	0.1376	0.0118	0.0002
	Sign	0.0962	0.0089	0.0004	0.0001	0.0009
	Signed Rank	0.7033	0.1019	0.0531	0.0074	0.0005
Quantiles	Max	2.60570	5.4231	13.87750	11.59400	11.59990
	75%	0.40775	0.9222	1.35925	1.77630	1.88600
	50%	-0.00270	-0.0805	-0.25865	-0.43860	-0.87515
	25%	-0.39190	-1.0403	-1.70475	-2.63420	-3.91120
	Min	-3.20470	-6.7184	-9.76260	-13.46940	-17.40590

Table 8: Univariate Statistics for Vertical Error and Level Flight

Vertical Error Level Flight		Look Ahead Time 0	300	600	900	1200
Location	N	1300	994	704	500	340
	Mean	-0.31106	0.278877	-4.97225	-1.66935	-5.06999
	Median	0.00000	0.000000	0.00000	0.00000	0.00000
	Mode	0.00000	0.000000	0.00000	0.00000	0.00000
Variability	Std Dev	89.23579	160.86429	141.17816	188.73699	187.71764
	Variance	7963	25877	19931	35622	35238
	Range	2574	4166	2842	4166	3028
Moments	Skewness	2.65679858	1.99437499	-7.5590638	2.38197951	-5.0460949
	Kurtosis	124.726777	115.132715	111.82109	104.981745	67.5558017
Test for Location	Student T	0.9000	0.9564	0.3504	0.8433	0.6188
	Sign	0.8679	1.0000	1.0000	1.0000	1.0000
	Signed Rank	0.7233	0.9559	0.5186	1.0000	0.5781
Quantiles	Max	1511.4440	2453.2242	1134.83	2453.22	1134.832
	75%	0.0000	0.0000	0.00	0.00	0.000
	50%	0.0000	0.0000	0.00	0.00	0.000
	25%	0.0000	0.0000	0.00	0.00	0.000
	Min	-1062.4590	-1713.0851	-1706.71	-1713.09	-1892.755

Table 9: Univariate Statistics for Horizontal Error and Transition Flight

Horizontal Error Transition Flight		Look Ahead Time 0	300	600	900	1200
Location	N	517	105	18	3	No Data
	Mean	-0.04768	-0.37635	-0.93441	0.104033	
	Median	-0.00310	-0.26180	-0.39120	0.210700	
	Mode	0.00000	-0.99300	.	.	
Variability	Std Dev	0.47859	0.96192	1.91927	0.32663	
	Variance	0.22905	0.92529	3.68360	0.10669	
	Range	8.56060	5.32020	8.72040	0.62660	
Moments	Skewness	-5.4372482	-0.6159797	-0.2918505	-1.3128132	
	Kurtosis	76.0116226	1.27669484	1.38594756	.	
Test for Location	Student T	0.0239	0.0001	0.0545	0.6366	
	Sign	0.0009	0.0004	0.0309	1.0000	
	Signed Rank	0.0010	0.0001	0.0304	0.7500	
Quantiles	Max	1.7939	1.9640	3.2989	0.3640	
	75%	0.0430	0.0864	-0.0914	0.3640	
	50%	-0.0031	-0.2618	-0.3912	0.2107	
	25%	-0.1211	-0.7965	-2.1508	-0.2626	
	Min	-6.7667	-3.3562	-5.4215	-0.2626	

Table 10: Univariate Statistics for Lateral Error and Transition Flight

Lateral Error Transition Flight		Look Ahead Time 0	300	600	900	1200
Location	N	517	105	18	3	No Data
	Mean	0.019010	-0.00023	-0.01995	0	
	Median	0.000000	0.00000	0.00000	0	
	Mode	0.000000	0.00000	0.00000	0	
Variability	Std Dev	0.19165	0.08322	0.07427	0	
	Variance	0.03673	0.00693	0.00552	0	
	Range	3.93080	0.98070	0.31630	0	
Moments	Skewness	5.40872583	-6.9666959	-4.0983321	.	
	Kurtosis	76.3451553	68.5649436	17.0537141	.	
Test for Location	Student T	0.0245	0.9778	0.2702	.	
	Sign	0.0945	0.7428	0.6875	.	
	Signed Rank	0.5390	0.8620	0.4375	.	
Quantiles	Max	2.2576	0.2214	0.0021	0	
	75%	0.0000	0.0000	0.0000	0	
	50%	0.0000	0.0000	0.0000	0	
	25%	0.0000	0.0000	0.0000	0	
	Min	-1.6732	-0.7593	-0.3142	0	

Table 11: Univariate Statistics for Longitudinal Error and Transition Flight

Longitudinal Error Transition Flight		Look Ahead Time 0	300	600	900	1200
Location	N	517	105	18	3	No Data
	Mean	-0.08062	-0.36386	-1.15551	-1.10760	
	Median	-0.00520	-0.18120	-1.08910	-1.69350	
	Mode	0.00000	.	.	.	
Variability	Std Dev	0.70186	1.62363	2.89342	1.28323	
	Variance	0.49260	2.63618	8.37188	1.64667	
	Range	9.32150	8.41780	9.13690	2.35730	
Moments	Skewness	-1.9989218	0.04245713	-0.0545933	1.62629986	
	Kurtosis	17.6693391	-0.2384859	-0.9437865	.	
Test for Location	Student T	0.0093	0.0237	0.1084	0.2735	
	Sign	0.1204	0.4351	0.4807	1.0000	
	Signed Rank	0.0144	0.0341	0.1540	0.5000	
Quantiles	Max	2.5125	4.2903	3.5332	0.3640	
	75%	0.1507	0.6772	0.7217	0.3640	
	50%	-0.0052	-0.1812	-1.0891	-1.6935	
	25%	-0.3091	-1.6804	-3.1840	-1.9933	
	Min	-6.8090	-4.1275	-5.6037	-1.9933	

Table 12: Univariate Statistics for Vertical Error and Transition Flight

Vertical Error Transition Flight		Look Ahead Time 0	300	600	900	1200
Location	N	517	105	18	3	No Data
	Mean	22.70613	111.0935	146.7713	0	
	Median	0.00000	0.0000	0.0000	0	
	Mode	0.00000	0.0000	0.0000	0	
Variability	Std Dev	347.19151	508.56087	447.86152	0	
	Variance	120542	258634	200580	0	
	Range	3363	3417	1723	0	
Moments	Skewness	0.81433016	-0.0250381	2.52242613	.	
	Kurtosis	7.46480201	3.45091494	6.03224633	.	
Test for Location	Student T	0.1376	0.0273	0.1823	.	
	Sign	1.0000	0.3082	1.0000	.	
	Signed Rank	0.6258	0.0319	0.8984	.	
Quantiles	Max	1941.8109	1459.3556	1563.0761	0	
	75%	35.1568	197.8320	8.6446	0	
	50%	0.0000	0.0000	0.0000	0	
	25%	-26.6666	-43.8752	-10.0502	0	
	Min	-1420.7829	-1957.5000	-159.8362	0	